

# COMFORT CONDITIONS IN A HABITAT FOR HUMANITY HOUSE IN CENTRAL TEXAS

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## ABSTRACT

This paper presents preliminary results of an analysis of measured comfort conditions for a Habitat for humanity house in central Texas. In the case study house indoor-outdoor temperature, humidity and CO<sub>2</sub> levels have been monitored in an attempt to ascertain how comfort levels are being maintained. Temperature measurements of the slab in three locations have also proved useful in determining the impact of cold floors in the wintertime. This paper presents an analysis of the findings and recommendations concerning future design modifications that could make the Habitat houses more comfortable without substantially raising costs.

## INTRODUCTION

Habitat for Humanity is an international, volunteer, religious organization that has been established to develop affordable, low cost housing. Habitat homes are low cost, high quality, energy efficient houses constructed with volunteer labor and materials that utilize no or low interest loans to keep monthly payments low. Qualified Habitat homeowners are required to participate in the construction of their homes. Their "sweat equity" also keeps the cost of the homes low. Habitat for Humanity provides services to homeowners from local offices located in all 50 of the United States and in 51 countries around the world (Habitat 2000).

The design of each Habitat home varies with location with the overall goal of providing a low cost, energy efficient, durable home. Several efforts have been performed to evaluate the effectiveness of the energy efficiency features in selected Habitat homes in hot and humid locations including efforts in Texas (Haberl et al. 1998a, 1998b) and Florida (Parker et al. 1996; 1997; 1998). These reports have shown that efficient equipment selection, selected envelope measures (i.e., white roofs), and overall construction quality as effective energy conserving measures for Habitat houses located in hot and humid climates.

However, all the previous efforts have assumed that the indoor environments in the Habitat houses are comfortable and healthy and/or performed a limited analysis of the indoor conditions. This paper reports on efforts to investigate the indoor environment of a monitored Habitat for Humanity house in central Texas.

## METHODOLOGY

### Background

The Habitat for Humanity house used in this study is a single-story 1048 ft<sup>2</sup>, three-bedroom house with an attic space (Figure 1) and is located in Bryan, Texas. The measured data are recorded with an on-site data logger that was installed during the 1997 construction period. The house consists of a kitchen/dining area, utility room and two bathrooms. The house has a 64ft<sup>2</sup> front porch and a 42ft<sup>2</sup> patio at the rear of the house.



**Figure 1:** Case Study Habitat House. This photo shows the front (north side) of the case study house shortly after construction was completed.

The house is constructed with 4-inch concrete slab-on-grade with grade beams at 10-foot centers laid over an impermeable vapor barrier. The exterior 2 x 4 stud walls (16 inch O.C.) are composed of ½ inch gypsum, R-13 blown-in cellulose insulation, ½ inch foil-faced foam-board insulation, Tyvek water barrier, and vinyl siding. The ceiling is ½ inch gypsum supported by 2 x 6 inch joists (24 inch O.C.),

R-19 blown-in fiberglass insulation, and R-6 duct insulation. The roof construction consists of composite shingles on felt underlayment, with a 5/8 inch plywood deck supported by 2 x 6 inch trusses (24 inch O.C.) and has an 18 inch overhang. The house's heating and cooling systems consists of a central, forced-air natural gas furnace and air conditioner.

A 50-channel data logger was installed during the construction of the house to record 15-minute energy and environmental conditions. Electrical monitoring includes the whole-house electricity, and sub-metering for the clothes dryer, air-conditioner, air-conditioner blower, refrigerator, freezer, clothes washer and dishwasher. Additional thermal metering includes the whole-building natural gas and thermal metering of the domestic water heater. Environmental metering include three ground temperatures beneath the house, indoor temperature, humidity and CO<sub>2</sub>, attic temperature and humidity, HVAC supply air temperature and humidity, and ambient temperature, humidity, CO<sub>2</sub>, horizontal solar and wind speed as indicated in Table 1.

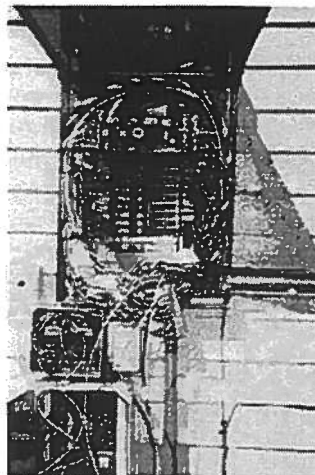
**Table 1: Energy and Environmental Channels Recorded by the Data Logger.** This table contains the channel descriptions from the data logger installed at the case study house. The channel types include power monitoring (KW), analog channels (AN), and digital channels (DIG).

| Description     | Channel |
|-----------------|---------|
| WHL HSE ELE-L1  | KW 0    |
| WHL HSE ELE-L2  | KW 1    |
| DRYER           | KW 2    |
| A/C             | KW 3    |
| A/C BLOWER      | KW 4    |
| REFRIGERATOR    | KW 5    |
| FREEZER         | KW 6    |
| CLOTHES WASHER  | KW 7    |
| DISHWASHER      | KW 8    |
| GND TEMP-NORTH  | AN 0    |
| GND TEMP-CENTER | AN 1    |
| GND TEMP-SOUTH  | AN 2    |
| RH-SUPPLY       | AN 3    |
| TEMP-SUPPLY     | AN 4    |
| RH-RETURN       | AN 5    |
| TEMP-RETURN     | AN 6    |
| CO2-INDOOR      | AN 7    |
| CO2-OUTDOOR     | AN 8    |
| SOLAR RADIATION | AN 9    |
| WIND SPEED      | AN 10   |
| RH-OUTDOOR      | AN 11   |
| TEMP-OUTDOOR    | AN 12   |
| RH-ATTIC        | AN 13   |
| TEMP-ATTIC      | AN 14   |
| FLOW METER      | DIG 0   |
| BTU METER       | DIG 1   |
| NATURAL GAS L-1 | DIG 2   |

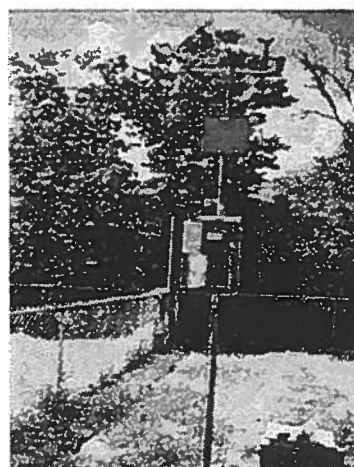
All sensors were calibrated against NIST-traceable instruments at the Energy Systems Laboratory (ESL) (Turner et al., 1992). Data from the data logger are downloaded weekly, inspected for errors and loaded into the ESL's relational database.

## PHOTOGRAPHS

Photos of the monitoring equipment are included in Figures 2-5. Figure 2 is a photo of the electrical panel for the case study house where the current transformers and voltage reference were installed.



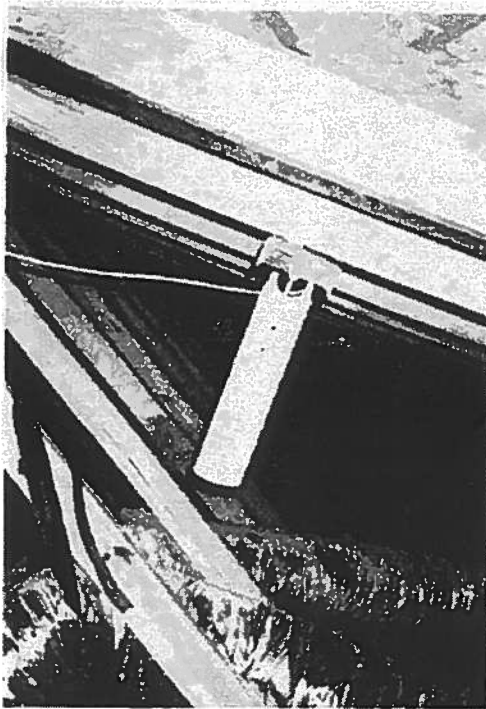
**Figure 2:** Electrical and Thermal sensors for the Case Study House. This photo shows the electrical panel for the case study house where the current transformers and voltage reference were installed. Directly below the distribution panel is the power supply for the logger and the Btu meter for the domestic water heater.



**Figure 3.** This is a photo of the data logger and weather station for the case study house located on a pole at the rear of the house to provide for easy access.



**Figure 4: Indoor Environmental Sensors.** This photo shows the indoor monitoring station for temperature, humidity and CO<sub>2</sub> located in the hallway return air plenum.



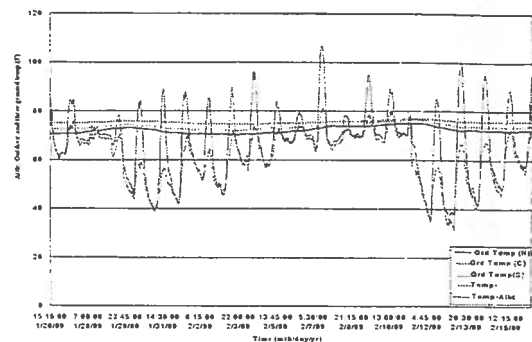
**Figure 5. Attic Temperature and Humidity Sensor.** This figure shows the combined temperature-humidity sensor and PVC radiation shield located in the attic of the case study house

Data, telephone and 24 VAC power are provided in buried conduit that runs between the house and the support pole. Figure 4 is a photo of the indoor monitoring station for temperature, humidity and CO<sub>2</sub> located in the hallway return air plenum. Figure 5 is a photo of the combined temperature-humidity sensor and PVC radiation shield located in the attic of the case study house.

## RESULTS

### Temperature measurements.

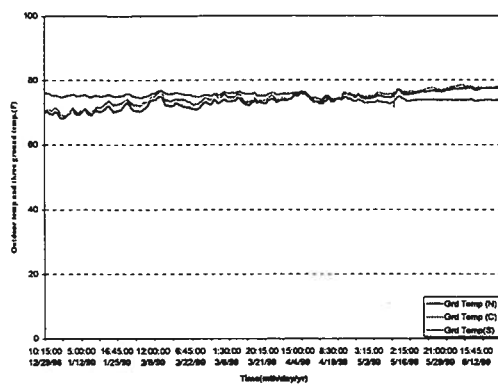
Preliminary results of the monitoring efforts are included in Figures 6 to 13. Figure 6 shows measured 15-minute temperatures from the attic,



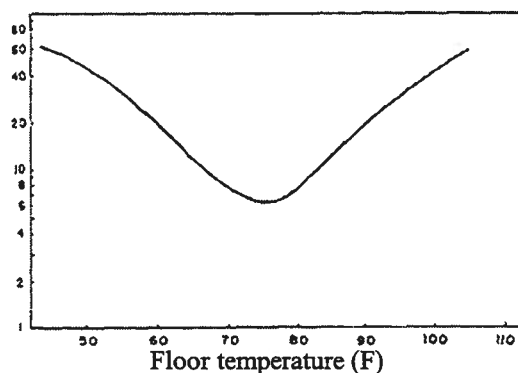
**Figure 6: 15-minute Environmental Temperatures Measured at the Case Study House.** This figure shows measured 15-minute temperatures from the attic, ambient, and indoor air sensors, along with ground temperatures located below the slab in the center of the house [C], and 3 feet from the edge of the slab on the [N] and south [S] sides.

ambient, and indoor air sensors, along with ground temperatures located below the slab in the center of the house [C], and 3 feet from the edge of the slab on the [N] and south [S] sides for a three week period in January-February 1999. It is clear from figure 6 that the ceiling and walls of the house are exposed to significant variations in diurnal exterior temperatures with ambient wall temperatures varying from 30 F to 80 F and attic temperatures varying from 30 F to over 100 F. The attic temperatures rise significantly above the ambient temperatures during the daytime, as the solar heat gain penetrates the surface of the roof. However, the attic temperatures almost always drop to the same temperature as the ambient temperatures each evening – an effect of night sky radiation and the vented attic. The elevated attic temperatures contribute to the duct heat gain during the cooling season, and to a lesser extent, contribute to the space heat gain because of the R-19 insulation.

During this same period the measured ground temperatures directly below the concrete slab varied little with the center of the slab remaining the closest to the indoor air temperature. The temperatures near the edges of the slab are slightly lower than the central slab temperature indicating the uninsulated edges of the concrete slab are allowing the exterior cold temperatures to penetrate into the interior of the house. Figure 7 shows measured ground temperatures located below the slab in the center of the house [C], and 3 feet from the edge of the slab on the [N] and south [S] sides for a 6-month period from December 1998 to June 1999. These measured temperatures clearly show that there are significant periods in the winter when the edges of the concrete slab are well



**Figure 7:** Daily Ground Temperatures Measured at the Case Study House. This figure shows measured ground temperatures located below the slab in the center of the house [C], and 3 feet from the edge of the slab on the [N] and south [S] sides for a 6 month period from December 1998 to June 1999.



**Figure 8:** Percentage of people dissatisfied as a function of floor temperature.

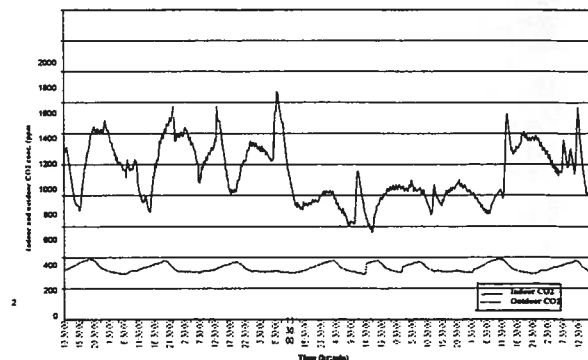
below the 77°F recommended by ASHRAE for bare feet in contact with an uncarpeted floor (Figure 8).

Several other features are evident as well from Figures 6 and 7. First, in Figure 6 during the three-week period that is shown there was a warming period in the middle of February followed by 40+ F

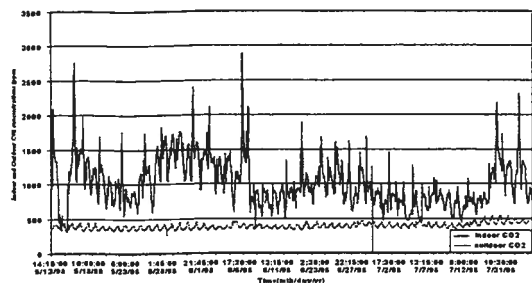
drop in temperature on February 11<sup>th</sup>. During the warming period the slab temperatures converged towards the room temperature. Whereas, one day following the outdoor temperature drop the temperatures at the edges of the slab started to drop away from the center slab temperature. Second, in Figure 7 the temperature of the center of the slab remains relatively constant throughout the 6-month period due to the direct contact with the conditioned air in the building. Finally, the edges of the slab vary from about 60°F in the middle of the winter to almost 80°F by the summer, indicating a significant influence from the outdoor temperature.

### CO<sub>2</sub> measurements.

Figures 9 and 10 show measured indoor-outdoor CO<sub>2</sub> concentrations. Figure 9 shows 15-minute measured indoor and outdoor CO<sub>2</sub> concentrations for one week for the period 12/28/98 to 1/5/99. Clearly, there are significant periods when the house is well above the 1,000 ppm recommended by ASHRAE. Figure 10 shows 15-minute measured indoor and outdoor CO<sub>2</sub> concentrations for the 2-1/2 month period from 5/13/98 to 7/31/98. During this period, there is a period of 10 days when the indoor CO<sub>2</sub> concentration never falls below 1,000 ppm and isolated spikes when the CO<sub>2</sub> concentrations topped 2,500 ppm. However, there are also periods when the CO<sub>2</sub> concentrations did not rise above 1,000 and a few days when the indoor CO<sub>2</sub> concentrations matched the outdoor concentrations. Clearly, one can conclude from these data that the CO<sub>2</sub> concentrations are very dependent upon how many people are in the house and whether or not the house has any windows open.



**Figure 9:** 15-minute Measured Indoor and Outdoor CO<sub>2</sub> Concentrations. This figure shows measured 15-minute indoor-outdoor CO<sub>2</sub> concentrations from the case study house for the period 12/28/98 to 1/5/99.

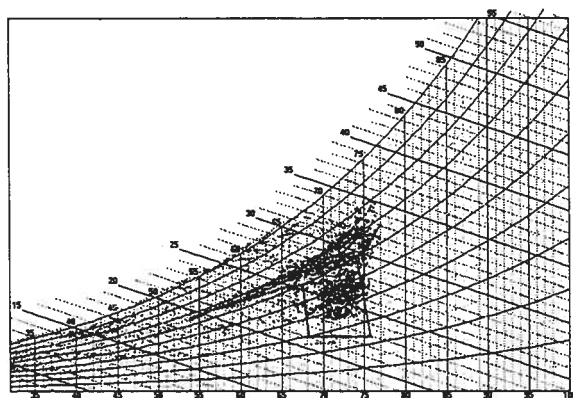


**Figure 10:** 15-minute Measured Indoor and Outdoor CO<sub>2</sub> Concentrations. This figure shows one week of measured 15-minute indoor-outdoor CO<sub>2</sub> concentrations from the case study house for the period 5/13/98 to 7/31/98.

#### Temperature-humidity measurements.

Indoor temperature-humidity measurements were also recorded to help analyze the thermal comfort of the house as shown in Figures 11 and 12. In Figure 11 the indoor-outdoor temperature and humidity are displayed on the psychrometric chart for the 3-month period from January 1999 to March 1999. Figure 12 shows the indoor-outdoor temperature and humidity for the Month of August 1999.

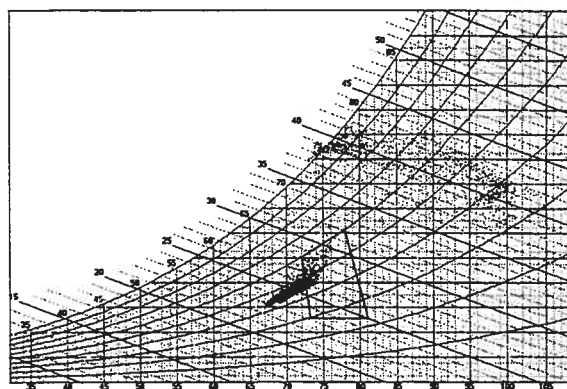
During the heating mode (Figure 11) several features can be seen in the data. First, there are two distinct indoor temperature-humidity groups: one group where the heating system was clearly operating and the resultant temperature-humidity condition stayed within the confines of the ASHRAE comfort chart for heating (i.e., 60% RH, 68 – 75°F and 36 Twb).



**Figure 11:** Indoor/outdoor temperature and humidity displayed on the psychrometric chart (heating mode). This figure shows the measured indoor temperature-humidity displayed on the psychrometric chart during the heating season for the period January to March 1999.

The second mode is a group of indoor temperature-humidity data that fall outside the comfort zone and represent either a) periods when ambient temperatures were cold but the heating system was not active (i.e., temperatures colder than the comfort zone), or b) periods when the humidity levels are above the 60% RH recommended by ASHRAE for mold and mildew control.

During the cooling season (Figure 12), a dramatically different picture emerges about the indoor comfort conditions. In this period, which represents the month of August 1999, ambient conditions varied from 75°F to 100°F and were always more humid than the ASHRAE comfort zone, forcing the Habitat homeowner to continuously run her air conditioner. This continuous air-conditioning produced a very tight grouping of the indoor temperature-humidity measurements that range from 65 to 75°F and remained almost entirely within a 40 to 50% RH band.



**Figure 12:** Indoor/outdoor temperature and humidity displayed on the psychrometric chart (cooling mode). This figure shows the measured indoor temperature-humidity displayed on the psychrometric chart during the cooling season for the month of August 1999.

#### DISCUSSION

This paper has presented preliminary results of efforts to measure the energy use and environmental conditions of a Habitat for Humanity house in central Texas. In general, these measurements show that the Habitat house is providing year-around comfort conditions for the homeowner. However, a closer look at the data reveals the following features:

- 1) The attic temperatures are hot during sunny days even in the winter and very hot during sunny days at other periods. Therefore, it is recommended that alternative designs be investigated that will avoid placing air-conditioning equipment and ductwork in

the attic where it is exposed to the extreme temperature.

2) Slab temperatures at the edge of the slab are dropping well below the 77°F floor temperature recommended by ASHRAE for bare feet on uncarpeted concrete floors. This may be indicating the need for perimeter insulation. This recommendation runs counter to ASHRAE Standard 90.1 and 90.2. Both of these standards recommend levels of insulation based upon cost effective heat loss mitigation. However, the measurements reported in this paper would indicate that insulation should be recommended based upon comfort conditions. Additional study is also needed to determine the interaction of winter-time thermostat settings and the insulated slab temperatures for optimum comfort conditions. For example the indoor air temperatures were 72-75°F and to as low as 55°F, which would indicate a need for slab heating in order to maintain the 77°F temperature

3) Interior comfort conditions vary during the heating season. The Habitat homeowner in the case study house allows the temperatures to drop as low as 55°F during the heating season. This may also be contributing to low slab temperatures. High humidity conditions have been observed for the heating season as well. When the heating system is on it does appear to maintain temperatures at or near the ASHRAE recommended conditions.

4) Interior comfort conditions are well maintained during the cooling season. Indoor comfort conditions during periods of continuous air-conditioning are well below the 60% RH ASHRAE recommended humidity limit for mold and mildew control. Measurements reveal that the homeowner in the case study house prefers indoor temperatures well below the ASHRAE recommended temperatures.

5) Indoor-outdoor CO<sub>2</sub> measurements indicate higher than expected indoor CO<sub>2</sub> concentrations and may be indicating that the house is too tight and in need of a ventilation system during the peak cooling period. This is also confirmed by blower door measurements that showed 0.3 to 0.5 ACH at 50 Pascals. Indoor CO<sub>2</sub> levels seem to be influenced by door-window opening or closing, use of exhaust fans and number of occupants. CO<sub>2</sub> levels tend to be higher in the summer (less infiltration due to stack effect). Obviously, during the monitoring period there were periods when the homeowner opened the windows and the CO<sub>2</sub> levels approached the ambient levels.

#### ACKNOWLEDGMENTS

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